Summary and Inflammation (P.O.)

Achn: SOLAL TTF Momentum Group

→ Momentum Transport

- something old → von physics
  \[ \Pi \Theta, NW, \text{etc} \]

- something new → Vector → II (Transport)
  Reynolds Tensor

"stresses" understanding of:

→ cross phase
  - II structure \( \langle \vec{v}_1 \vec{v}_n \rangle \) → fluid
  - \( \langle \vec{v}_1 \vec{v}_n \rangle \) \( \langle \vec{u} \vec{d} \vec{v}_n \rangle \) → kinetic (II acceleration)

\* → (symmetry breaking)
  - \( \langle \vec{v}_E \rangle \)
  - poloidal asymmetry \( \text{edge of} \) and FDE coupling

- studied intensively in solar astrophysics
- climate, oceanography, atmospheric

⇒ good source for outside preview speakers...
structure of Momentum Flux \[ \{ \langle \nabla \cdot \mathbf{v} \rangle \} \]

\[ \Pi = -\chi_{i} \mathcal{G} \langle \mathbf{v}_{ii} \rangle + \nabla \langle \mathbf{v}_{ii} \rangle + \mathcal{S} \quad \text{(new)} \]

\[ \rightarrow \text{"Residual Stress"} \]

\[ \sim \chi_{i} \left\{ \begin{array}{l}
\text{convective} \\
\text{TEP} \\
\text{thermo-electric}
\end{array} \right. \]

\[ \nabla \langle \mathbf{v}_{ii} \rangle / \beta^{3} \quad \text{adverted} \]

\[ \text{Yoshida} \]

\[ \text{dependent upon mode propagation symmetry breaking, resonant vs. non-resonant, etc.} \]

\[ \text{Issue: How think beyond } \mathcal{O}, \mathcal{V} \text{?} \]

\[ \text{i.e. - perturbation experiments (dual)} \]

\[ \text{in } \nabla \langle \mathbf{v} \rangle \text{ and } \partial_{T}, \partial_{N} - \text{HARD} \]

\[ \Delta n \text{ as offset?} \]

\[ \text{(Solomon)} \]

\[ \text{Issue: How address cross-phase? - (Hidel, et al)} \]

\[ \text{(Basic Experiments) ??} \]
Intrinsic Rotation

the big mystery, ...

Frequently linked to \( \langle V_{E} \rangle \) in theory

"look" of a bifurcation

C-Mod, ITPA database (Rice)

\( \rightarrow \) L-H transition

\( \rightarrow \) develops from edge

BUT

"2 Looks!"

TCV (Bortolon)

threshold, \( \sim \) OH saturation

Spin bifurcation - core event

- no \( T \) rise?!

Cartoon Summary of Theory

\[ S' \sim (V_{ph}) \langle V_{E} \rangle \sim I \]

Critical parameter

residual stress

\( \alpha \sim 2 \)

\( \rightarrow \) C-Mod \( \rightarrow \) transport bifurcation via \( V_{E} \)

\( \rightarrow \) TCV \( \rightarrow \) \( V_{ph} \) 'bifurcation', \( \langle V_{E} \rangle \) inst.

"spin" \& "transport"

\( \rightarrow \) \( V_{k} \) \( \rightarrow \) \( V_{k} \) inst.

Hysteresis \( \rightarrow \) turbulence spreading?
Issues:
1. Other types?
   - dual behavior
   - spin bifurcations

ITB formation → ?
   → edge
   → core

Fluctuation studies?
- \( \langle V_E \rangle' \) → resolution (?)
  - \( V_{ph} \) change → resolution (?)
  - \( \langle V_E \rangle' \) → induced reduction

Elucidate physics of cross-phase

Perturbation experiments
- spin-up bifurcation fronts ?!
  - track via fluctuations
  - elucidate:
    - "true" bifurcation ? → SLOW TRANSITIONS
    - \( T \to \infty \) at transition
    - hysteresis ?
Perturbation, cont'd

→ explore \( L \to H \to L \ldots \) cyclic perturbation

(4) Edge as origin of \( \left\{ \text{symmetry breaking} \right\}\)

→ many candidates

to explore \ldots
Momentum transported via blob events (Myra, Coppi)

Edge is strongly turbulent, bursty and intermittent (Boedo, Zweben, ...)

Stationarity (??)

SOL flows (C.T. Chang, et al.)

C-mod strongly suggests spin-up initiated at edge [Lee, PRL, 03]

Source (??)

Direct particle wave momentum losses

ER structure in/out LFS (Hinton)

Neo-classical polarization effects ?

Neutral friction => no slip (TCV)

Boundary condition (??)

Poloidal plasma asymmetries, strong ballooning, GAMS, ...

X-point configuration, field ripple (JT60U, TS); other magnets ...

\[ \lambda^e \sim L \rightarrow L-H transition \]

Symmetry breaking evident at edge (i)

Edge Plasma Dynamics crucial to Spontaneous Rotation
Core Rotation Profiles $\leftrightarrow$ Evolution

Issue: Difficult (rather complicated)

- TE$ \rightarrow \{ \nu_n \}$ correlated, strongly
  $\Rightarrow$ dual $(^1)$ perturbation experiments
  $\Rightarrow$ compare $(\Delta T/T) - (\Delta T/T)_{\text{crit}}$ cases
- Vhe (i.e. CTEM) dominated regime as clearest case $\Rightarrow$ electron heating perturbation?

- Can experiment elucidate what is "natural" variable?

Issue: $\Omega \varphi$ as double agent?
  $\Rightarrow$ $<E\varphi>$ $\Rightarrow$ (good)
  $\Rightarrow$ shear flow instab $\Rightarrow$ (bad)

- Can $\Omega_{III} - D$ elucidate differences between Hybrid Mode scans and "Solomon" scans, even qualitatively?
Poloidal Momentum Transport (all issues)
- basic physics drives O.D.5 etc.
  ↔ cross-phase in vorticity flux...?
- toroidal ↔ poloidal link → \( \langle UE \rangle \)
  and what else?
- Perturbations, again:
  \( \langle V_o \rangle \) pulse from prompt torque?

⇒ understand departure of \( \langle V_o \rangle \)
  from neo-classical expectations

⇒ Neo-classical Theory / Effects (Theory, Issue)
- tools developing to go beyond
  simple theory to cases of complicated geometry – i.e. GTGNeo
- need interface/couple
  turbulence + neo-classical transport tools
  - poloidal momentum
  - transport near marginality
Theory and Simulation
improve models, geometry...
- till now, largely fluid, electrostatic

need face/address:
- wave transport channel (P.D.)
- EM
- resonant particles

\( \frac{E \Omega}{W \Omega} = NR \) PMD
\( EM \Rightarrow W \Omega = NR \) PMD + Field, MA

2. resonant particles demand precise
treatment of cross-phase

3. Momentum transport from \( \sum \) wave prop,
EM, EP modes
\( \Rightarrow \) all issues for ITER \{ EP + turb. \\
\( \Rightarrow \) HA\W \rightarrow \) parallel propagation
\( \Rightarrow \) \( \Pi_{\|} \) II for waves

\( \tilde{B}_r \rightarrow \) wave momentum
\( \langle \tilde{B}_r \hat{P}_\| \rangle \) (fluttering) field
Last and least - Simulation.... (especially Gh)

- Gh simulation has contributed little (if any) to understanding momentum transport by turbulence....

- No where to go but up! How?

- How extract info re: transport, especially $\partial_j V \times S$ interplay from DF simulation?

- How address cross-phase self-consistently?

- What might be gained from simpler models - i.e. GF?